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Stored product protection in Africa: Past, present and future

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DOI: 10.5073/jka.2010.425.177

Abstract

More than 55% of Africans earn their livelihood from agriculture, which is also the key to economic development of the continent. The agriculture is largely traditional and grains constitute the bulk of food production. Sorghum, maize, rice, wheat and millet for cereals and cowpeas, dry beans, groundnut, chickpea and bambara groundnut for pulses, are most common in Africa. Because agricultural production is seasonal while the demands for agricultural commodities are more evenly spread throughout the year, grain storage becomes a particularly important agricultural activity. Grain storage is done on-farm, peasant farmers' residences (family granaries), community stores and large warehouses. Since most of the grains produced in Africa are destined for human consumption, storage in family granaries predominates. Unfortunately, the technology and management of family granaries and other storage structures are seriously wanting. These predispose the grains to serious attacks from biotic constraints such as insects, rodents, birds and micro-organisms. The rate of insect proliferation in these storage structures could be alarmingly high, especially with the warm climate in tropical Africa. Annual grain losses of up to 50% in cereals and 100% in pulses have been reported, although average losses stand at roughly 20%. Major insects that attack cereals and pulses include grain weevils, grain borers, grain beetles and grain moths. Pest prevention, early detection and pest control would greatly reduce grain losses during storage. Control methods comprise physical, chemical and phytochemical measures with emphasis on the use of traditional botanical pesticides. This paper discusses the major cereals and pulses stored in Africa, the different storage structures, storage losses, constraints, control measures, and the relationship between storage structures and pest infestation. It also attempts to highlight peculiarities to the African storage environment and research trends over the years, and suggests recommendations for improving grain storage in the continent.

Keywords: Stored products, Grains, Pests, Protection, Africa

1. Introduction

Over half of Africans earn their livelihood from agriculture, which is also the most important enterprise and key to economic development of the continent. Paradoxically, tropical African countries are among the world leaders in food insecurity (Pantenius, 1987; Ngamo and Hance, 2007). Almost 33% of the African population, some 200 million people, is malnourished. Food security could be achieved by increasing agricultural productivity and reducing pre- and post-harvest crop losses.

Agriculture in Africa is largely traditional and grains constitute the bulk of food production. Many cereals and pulses are grown in the continent but maize, sorghum, rice, wheat and millet for the former and cowpea, groundnut, common bean, soybean, chickpea, bambara groundnut, pigeon pea, and green gram for the latter, are most common. However, the dominant crops vary from one country to the other. Agricultural production is seasonal while demands for agricultural commodities are more evenly spread throughout the year. In this circumstance, crop storage becomes particularly important.

Storage is a way or process by which agricultural products or produce are kept for future use, it is an interim and repeated phase during transit of agricultural produce from producers to processors and its products from processors to consumers (Thamaga-Chitja et al., 2004). Grains need to be stored from one harvest to the next in order to maintain its constant supply all year round and to preserve its quality until required for use. For small scale farmers in Africa, the main purpose of storage is to ensure household food supplies (reserves) and seed for planting (Adetunji, 2007). The stored crop is gradually released to the market during off-season periods, which also stabilizes seasonal prices (Adejumo and Raji, 2007). In the dry Sahelian countries in the northwest of Africa, crop storage is a matter of subsistence and survival (Mikolo et al., 2007).

Three techniques of storage involving different structures have been identified in Africa (Adesuyi et al., 1980; Udoh et al., 2000), namely: traditional/local grain storage at the farm and domestic level which includes local cribs and rhombus, platforms, open fields, roofs and fire places; improved/semi modern grain storage techniques at farm and domestic level which are ventilated cribs, improved rhombus and brick bins; and modern centralized storage at the commercial level involving silos and warehouses. Since farming is mostly done by subsistence farmers, the first two storage techniques predominate. Stored grains may suffer from serious attacks from pests (insects, fungi, rodents and birds), especially when not protected and in the presence of poor store hygiene.

In the tropical countries, Hill (1975) listed 407 insect species of major and 788 of minor importance occurring in 48 major groups on stored products. Fleurat-Lessard (1988) stated that all grain and seed insect species belong to two principal orders: Coleoptera and Lepidoptera, with some minor species belonging to the order Psocoptera. Traditionally, the grain weevils, *Sitophilus* spp. (Coleoptera: Curculionidae) and the Angoumois grain moth, Sitotroga cerealella (Olivier) (Lepidoptera: Gelechiidae) on cereals and three genera of bruchids, Acanthoscelides, Zabrotes and Callosobruchus spp. on pulses are the most important pests of stored grain in Africa (Abate et al., 2000). In addition to direct destruction of grains through feeding and reproduction, insects' presence has direct influence on grains causing an increase in grain temperature and moisture contents which leads to an increase in respiration and consequently loss in quantity and quality of the grain (Odogola, 1994). Grain losses caused by insect pests in Africa are quite high and vary from country to country and from region to region. However, annual grain losses of over 50% (Abraham and Firdissa, 1991) in cereals and up to 100% (Boeke, 2002) in pulses have been reported, although the average stands at 20% (Youdeowi and Service, 1986; Philips and Throne, 2010). In general, the damage caused by insects is much higher than those caused by other agents like rodents and micro-organisms. Fungi are the major microorganisms causing spoilage in stored grains and seeds, resulting in significant losses to farmers, traders and food and feed manufacturers (Twiddy, 1994). The major grain storage fungi are Aspergillus, Fusarium and Penicillium spp. Rodent species that damage stored products when they are searching for food water or better leaving environments vary from region to region and from country to country. The three common species across Africa are the black rat, Rattus rattus, Fischer de Waldheim, brown rat, Rattus norvegicus, (Berkenhout) and common mouse, Mus musculus L. Pest control are mainly traditional and also the use of synthetic chemicals.

This review presents the major cereals and pulses stored in Africa, the different storage structures, storage losses, constraints, control measures, and the relationship between storage structures and pest infestation. It also attempts to highlight peculiarities to the African storage environment and research trends over the years, and suggests recommendations for improving grain storage in the continent.

2. Fundamentals of the African storage environment

2.1. Stored commodities

Generally, over 70% of grains harvested in Africa are stored for human consumption or for marketing (Mallamaire, 1965; Talabi, 1989). In the Sudan and Guinea Savanna of Nigeria 40-85% of grains harvested are stored (Ivbijaro, 1989). The commodities stored and their relative quantities are generally related to their production statistics - the higher the quantity produced, the more grains of that commodity stored. Familiarity with the map of the agro-ecological zones of Africa is important at this point since crop production patterns are related to the different zones (Fig. 1).

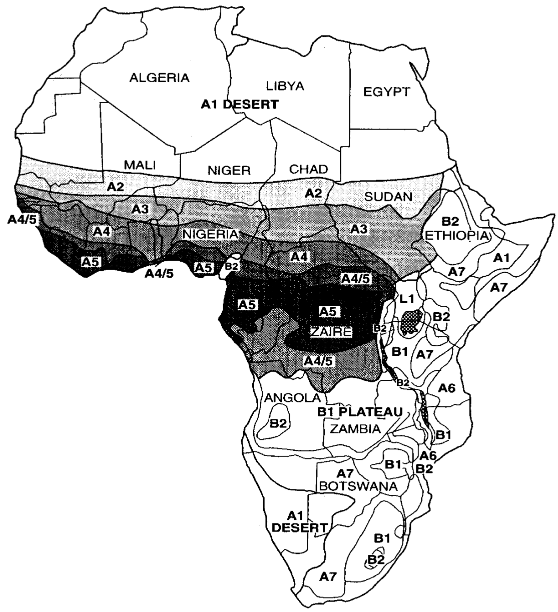


Figure 1 Major agro-ecological zones of sub-Saharan Africa (from Geddes, 1990): 1.) The Sahel (A2): characterized by erratic rainfall of 250 to 500 mm per annum, more than 8 months of dry season, and altitudes of less than 900 m above sea level. 2.) The Sudan savannah (A3): rainfall 500 to 900 mm, dry season 8 months, altitude less than 900 m above sea level. 3.) The Guinea savannah (A4): rainfall 900 to 1500 mm (mostly unimodal), dryseason of 5 to 7 months, altitude less than 900 m above sea level. 4.) The forest–savannah transition (A4/5): rainfall 1300 to 1800 mm (unimodal or bimodal), dry season of 4 months, altitude more than 900 m above sealevel. 5.) The forest (A5): rainfall 1500 to 4000 mm, virtually no dry season, altitude less than 900 m above sea level. 6.) The east coast (A6): rainfall 750 to 1500 mm (bimodal in some countries), altitude less than 900 m above sea level. 7.) The semi-arid east and south (A7): rainfall 250 to 750 mm, more than 8 months of dry season, altitude less than 1500 m above sea level. 8.) The plateaux (B7): rainfall 750 to 1500 mm (mostly unimodal), dry season 5 to 8 months, altitude 900 to 1500 m above sea level. 9.) The Uganda and Lake Victoria shore (L1): rainfall 1000 to 1500 mm (bimodal), altitude 1135 to 1300 m above sea level. 10.) The mountain (B2): rainfall 750 to 1800 mm (unimodal or bimodal), altitude more than 1500 m above sea level.

Cereals like maize, sorghum, rice, wheat, millet are important in many African countries, generally featuring among the first five cereals and first 15 crops in terms of production (Table 1) (FAOSTAT, 2007). Barley production is high in the Southern (3rd cereal and 17th crop) and Northern African countries (4th cereal and 12th crop). Oats appears to be common only in Lesotho (4th cereal and 9th crop) and teff in Ethiopia and Eritrea. Maize is the leading cereal crop across Africa, while millet and/or sorghum dominate in many countries in the drier areas of the continent like Burundi, Eritrea and Ethiopia in the east, Cameroon and Chad in the middle, Sudan in the north, and Nigeria, Niger, Ghana, Benin, Gambia, Burkina Faso, Senegal, Mali and Guinea in the West. In the dryer parts of Southern Africa (in Angola, Namibia, Zimbabwe, Botswana, Zambia and South Africa), millet is traditionally grown as a staple and surpluses are hardly traded (Smith, 1991). The more developed and sophisticated countries in Africa, characterized by arid or semi-arid sub-tropical warm climate like South Africa (2nd cereal and 4th crop) in the south and most of the countries in the north (Algeria (1st cereal and 1st crop), Egypt (1st cereal and 3rd crop), Libya (1st cereal and 8th crop), Morocco (1st cereal and 2nd crop), Tunisia (1st cereal and 1st crop), wheat is a dominant cereal crop (FAOSTAT, 2007). Wheat production is also high in Ethiopia (1st cereal and 4th crop), Kenya (2nd cereal and 15th crop), Sudan (2nd cereal and 3rd crop) and Zambia (2nd cereal and 5th crop).

Table 1 The top four cereal crops in Africa

Area	Crop	Production	Ranking[a]
World	maize	788112128	1 (2)
Africa		47229918	1 (3)
Eastern Africa		18578052	1 (3)
Middle Africa		3012277	1 (2)
Northern Africa		6412794	3 (8)
Southern Africa		7275806	1 (2)
Western Africa		11950989	3 (5)
World	sorghum	minor	minor
Africa		25134711	2 (5)
Eastern Africa		4505970	3 (10)
Middle Africa		1127801	2 (10)
Northern Africa		5857965	3 (8)
Southern Africa		215712	5 (18)
Western Africa		13427263	2 (4)
World	rice	657413530	2 (3)
Africa		20883913	3 (7)
Eastern Africa		4965075	2 (9)
Middle Africa		536359	5 (15)
Northern Africa		6933280	2 (5)
Southern Africa		minor	minor
Western Africa		8445829	4 (6)
World	wheat	611101664	3 (4)
Africa		18590367	4 (8)
Eastern Africa		3774128	4 (12)
Middle Africa		minor	minor
Northern Africa		13630393	1 (2)
Southern Africa		1922026	2(4)
Western Africa		1922026	2(4)

Compiled from FAOSTAT 2007; [a] Figure without bracket is rank among cereal crops and figure within brackets is rank among all crops

Cowpea, groundnut, common bean, soybean, chickpea, bambara groundnut, pigeon pea and green gram are the more common pulses grown in Africa. Nigeria (2,800,000 Mt), Niger (1,001,139 Mt), Burkina Faso (253,190 Mt), Cameroon (95,000 Mt) and Kenya (83,251 Mt) are respectively the 1st, 2nd, 3rd, 5th and 6th producer of cowpea in the world (FAOSTAT, 2007). Tanzania (7th in the world), Uganda (8th), Kenya (9th), Rwanda (13th) and Ethiopia (15th) for dry bean, Ethiopia (1st), Chad (2nd), Tunisia (7th), South Africa (9th) and Tanzania (11th) for chickpea, Nigeria (3rd), Sudan (8th), Ghana (10th), Congo DR (11th) and Senegal (12th) for groundnut, Malawi (3rd), Kenya (4th), Uganda (5th), Tanzania (6th) (1st cereal and 2nd crop), and Congo DR (9th) for pigeon pea, and Nigeria (13th) and South Africa (19th) for soybean are the highest producing countries in Africa.

2.2. Length of storage

Grain storage periods generally range between 3 and 12 mo across Africa. The length of storage depends on the agro-ecological zone, ethnic group, the quantity of commodity stored, the storage condition, the crop variety stored, etc. (Hell et al., 2000; Ngamo et al., 2007). The length of storage of grains tends to be longer in the dryer areas of Africa. Ngamo et al. (2007) reported an increase in storage length from 3-8 months in the Sudano-Guinean Agro-ecology to over 24 months in the Sudano-Sahelian zone of Cameroon. In the Northern Guinea Savanna of Benin, maize is usually stored between 3 and 8 months and in the Sudan Savanna 7-12 months (Hell et al., 2000). Storage for 5-12 months is common in the

Forest/Savanna Mosaic and the Southern Guinea Savanna of Benin. In the Forest/Savanna Mosaic, a few farmers store maize for more than 12 months. In this area, dominated by the "Mina" ethnic group, the size of maize stores is used to assess the wealth and social prestige of their owners and maize can be stored for up to 3 years (Smith, 1991).

The length of grain storage in the Sudan and Guinea Savanna of Nigeria is between 5 and 12 mo, except for soybean with usually less than 5 months storage because of its high demand (Ivbijaro, 1989). However, a maximum storage period of between 7 and 10 years for sorghum and millet in the Sudan Savanna was recently reported by Adejumo and Raji (2007). In Namibia, Keyler (1996) reported that the fear of the effect of drought made farmers store grains from 4 to 6.5 years.

2.3. Storage structures

The structure used for grain storage depends on the level of storage: On-farm, village and city or central. On farm storage involves individuals, while village storage may implicate individuals (family granary) or a group of individuals (community stores) (Fig. 2). The city and central storage facilities include large warehouses and are usually own by government agencies or non-governmental organizations (national or international). They are usually built with expertise from the developed world. Since most grains in Africa are produced by rural farmers, storage at the farm/village level will be emphasized in this paper. It is also at this level that traditional structures typical to Africa could be better discerned.

Open Platform (Cameroon)

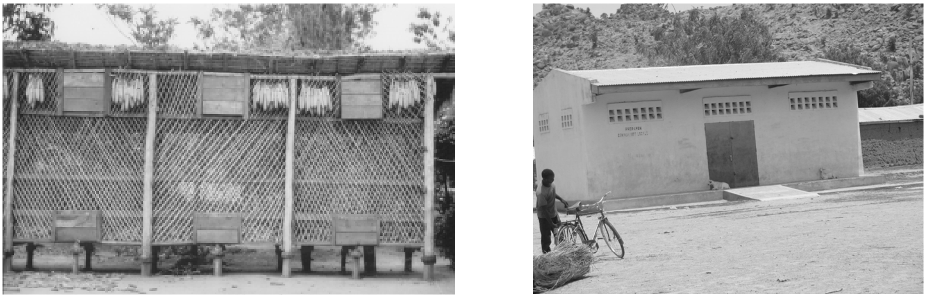
Woven basket (Cameroon)

Woven Basket (Burkina Faso)

Pots (Cameroon)

Mud Rhombu (Cameroon)

Mud Rhombu (Nigeria)



Maize Crib, Bamboo and straw roof (Madagascar) Community store (Cameroon)

Figure 2 Common storage structures in Africa.

Many publications have reported on traditional storage structures in Africa (Gilman and Boxall, 1974; Youdeowei and Serive, 1986; FAO, 1994; Adejumo and Raji, 2007). These storage facilities are made of local materials (plant materials and soil) and constructed by the villagers themselves. Some structures are used for temporary storage (mostly intended for the drying of the crop), while others are for long-term storage (FAO, 1994). Temporary storage methods are grouped into aerial storage (maize cobs or sorghum and millet panicles are sometimes tied in bundles, which are then suspended from tree branches, posts, or tight lines on or inside the house), storage on the ground, or on drying floors and open timber platforms. Long-term storage methods include (i) storage baskets (cribs or thatched rhombus) made exclusively of plant materials, (ii) calabashes, gourds, earthenware pots, etc., (iii) jars, (iv) solid wall bins (mud rhombus), and (v) underground storage.

In humid countries, where grain cannot be dried adequately prior to storage and needs to be kept well ventilated during the storage period, traditional granaries (cribs) are usually constructed entirely out of locally available plant materials: timber, reeds, bamboo, etc (Fig. 2). The small capacity containers (calabashes, gourds, earthenware pots, etc.) are most commonly used for storing seed and pulse grains, such as cowpeas. If the grain is dry (less than 12% moisture content) there is usually no problem with this kind of storage. Jars are generally kept in dwellings; they serve equally for storing seeds and legumes.

A solid wall bin or mud rhombus is a specially built structure from a mixture of clay and dry straw (Adejumo and Raji, 2007). It consists of a bin resting on large stones, timber or earth. Such grain stores are usually associated with dry climatic conditions, under which it is possible to reduce the moisture content of the harvested grain to a satisfactory level simply by sun-drying it. Solid wall bins are therefore traditional in the Sahel region of Africa, and in southern African countries bordering on the Kalahari Desert (FAO, 1994). Its shape could be spherical, circular or cylindrical (Adejumo and Raji, 2007).

Underground pit storage is practiced in the Sahelian countries and southern Africa, and is used in dry regions where the water table (low) does not endanger the contents. Conceived for long term storage, pits vary in capacity (from a few hundred kg to 200 t) (FAO, 1994). Their traditional form varies from region to region: they are usually cylindrical, spherical or amphoric in shape, but other types are known (Gilman and Boxall, 1974). The entrance to the pit may be closed either by heaping earth or sand onto a timber cover, or by a stone sealed with mud.

As with the length of storage, storage structures also vary with the agro-ecological zone, ethnic group, the quantity of commodity stored, the storage condition, etc. Description of the storage structures and habits in Benin and Namibia highlights some of these variations. Storage structures in the south of Benin (Southern Guinea Savanna) which has a bimodal rainfall pattern differ from the stores used in northern Benin (Northern Guinea Savanna and Sudan Savanna), where the rainfall is unimodal (Fiagan, 1994). In the south, stores are constructed out of plant materials, whereas in northern Benin a high percentage of stores are built of clay (Fiagan, 1994). Fiagan (1994) observed that the storage of maize in an intermediary structure may lead to the contamination of maize with pests and pathogens. Many farmers use two stores during the storage season, with the initial store built in the field (on-farm). Field stores are taken down in the dry season from February to April when bush fires and theft, because of depleting food stocks, might endanger the stored maize.

In Namibia, northern communal farmers store threshed grain either in granaries in the homestead, or inside the home in different types of containers (bags, baskets, drums, etc.). Traditional pearl millet storage in the Caprivi and Kavango regions, involves a variety of storage containers and structures, including granaries made of earth blocks or poles and mud, raised on a low platform and roofed with thatch. In the North Central Regions of Namibia, innovative grain storage containers are being made by farmers: small concrete “silos” (similar to a water reservoir) and thick baskets with lids made of Makalani palm leaves, Hyphaene petersiana Klotzsch ex Mart. Just as the husband and wife or wives have their own fields, they also have their own pearl millet storage places. The wife’s or wives’ pearl millet supplies are used first and only then that of the husband (Eirola and Bradley, 1990). Households of the North Central Regions own one or more granaries according to the size of their fields and quantity of pearl millet produced. When a family has only one granary, it is filled with the last harvest. If grain from the preceding year remains, it is placed on top of the new grain or placed in another container. But if a family has several granaries, the different harvests are kept separate.

2.4. Storage problems

All stocks constitute an entity made of the grain to be stored on one hand, and the environment where they evolve on the other hand, and where they are subjected to different attacks causing enormous losses. All of these losses are linked to two principal factors, which may be abiotic (granary architecture, humidity and temperature) or biotic (micro-organisms, rodents, birds and insects) (Scotti, 1978).

2.4.1. Abiotic factors

2.4.1.1. Storage structure architecture and management

The typical African traditional storage structures expose the grain to insect attack and favourable climatic conditions for their proliferation and those of micro-organisms and rodents. One of their major weaknesses is the presence of a single orifice for loading and removing grains, which also serves as an entry port for pests (FAO, 1994; Ngamo, 2000; Adejumo and Raji, 2007). The structures are generally not hermetically sealed giving room for pests to make their way into the structures. When constructed of plant materials, rodents easily destroy the structures and favour other sources of infestation (CIRAD, 2002).

Many authors have contended that a major cause of losses in traditional granaries is the lack of hygiene (Bell, 1996; Ngamo, 2000; Hoogland and Holen, 2001). At the time of filling the storage structure with newly harvested grain, the residues of old grain are not always completely removed, and these serve as a source of infestation for new grain. These impurities can attract pests from the exterior. Danho et al. (2003) showed that infested grain is attractive to pest insects, particularly to females for oviposition. Farmers in most areas of Eritrea keep old and new harvested grains in the same vicinity, which causes an easy migration or infestation of the new grains from the old grains (Haile, 2006).

2.4.1.2. Influence of climate

Humidity is the principal climatic element which acts in the storage system. Traditional cribs for example give room for limited air circulation, and when grain is not very dry there is an increase in grain moisture content in the structure (CIRAD, 2002). Biological activity occurs only when moisture is present. Therefore, moisture content of the product itself, as well as the moisture content of the surrounding air, is important for safe storage (Hayma, 2003). Stored products, as well as the organisms attacking stored products are living things: they breathe. During respiration ("breathing"), oxygen is used up and carbon dioxide, water and heat are produced. The rate of respiration, and thus the amount of carbon dioxide, water and heat that are produced is strongly dependent on the temperature and the moisture content of the product. Higher temperature and moisture content values of grains favours insect and fungus development and a decline in the germination capacity of the grains (Hayma, 2003).

2.4.2. Biotic factors

Living organisms like insects, rodents, birds (on-farm storage) and micro-organisms are serious constraints to the traditional storage systems of Africa (Ngamo, 2000; Nukenine et al., 2002; Haile, 2006). Amongst these living organisms, insects are responsible for the greatest storage losses in cereals and pulses.

The common insect pests reported in stored cereals and pulses are given in Table 2. However, traditionally the grain weevils (*Sitophilus* spp.) and the Angoumois grain moth (*Sitotroga cerealella*) on cereals and three genera of bruchids (*Acanthoscelides*, *Zabrotes* and *Callosobruchus*) on pulses are the most important pests of stored grain in Africa (Abate et al., 2000). *Callosobruchus chinensis* L. is the most important pest of chickpea in Eritrea (Haile, 2006). Wheat and sorghum in storage were attacked by *S. cerealella*, (Sitophilus spp.), confused flour beetles, *Tribolium confusum* Jacquelin du Val, sawtoothed grain beetles, *Oryzaephilus surinamensis* (L.) and mites (Haile, 2006). The most significant pearl millet pest in Namibia is reported to be *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae) (NRI, 1997). These moth infestations result in masses of grain held together by webbing (silk) produced by the larvae as they move through the grain seeking a pupation site. Many individual grains have their embryos removed by the feeding larvae. In order to use the grain, they have to be rubbed and sieved to remove the webbing, or alternatively the masses of clumped grain are fed to chickens (NRI, 1997).

Table 2 Common insect pests of stored cereals and pulses in Africa according to Mallamaire (1965), CAB International (1999), Mikolo et al. (2007) and Ngamo and Hance (2007)

No	Scientific name	Order	Family	Commodity	Country
1	*Lasioderma serricorne* F.	Coleoptera	Anobiidae	Some pulses and rice	Mostly East and West Africa
2	*Stegobium paniceum* L.	Coleoptera	Anobiidae	Some cereals and pulses	Mostly North Africa
3	*Araecerus fasciculatus* DeGeer	Coleoptera	Anthribidae	Some cereals and pulses	Mostly West African
4	*Prostephanus truncatus* Horn	Coleoptera	Bostrichidae	Maize and some pulses	Mostly West Africa
5	*Rhyzopertha dominica* F.	Coleoptera	Bostrichidae	Mainly cereals and some pulses	Mostly North and West Africa
6	*Acanthoscelides obtectus* Say	Coleoptera	Bruchidae	Beans, cowpeas	Mostly South and East Africa
7	*Bruchidius atrolineatus* (Pic)	Coleoptera	Bruchidae	Beans, cowpeas	East and West Africa
8	*Callosobruchus chinensis* L.	Coleoptera	Bruchidae	Primarily pulses	Mostly East Africa
9	*Callosobruchus maculatus* L.	Coleoptera	Bruchidae	Mainly cowpeas and some beans	Mostly East and West Africa
10	*Callosobruchus rhodesianus* (Pic)	Coleoptera	Bruchidae	Pulses	Cameroon, Kenya and Zimbabawe
11	*Callosobruchus subinotatus* (Pic)	Coleoptera	Bruchidae		Cameroon
12	*Caryedon gonagra* (F.)	Coleoptera	Bruchidae	Pulses	East and West Africa
13	*Sitophilus granarius* L.	Coleoptera	Curculionidae	Many cereals	Mostly North Africa
14	*Sitophilus oryzae* L.	Coleoptera	Curculionidae	Mainly cereals and some pulses	Across Africa
15	*Sitophilus zeamais* Motschulsky	Coleoptera	Curculionidae	Mainly cereals and some pulses	Across Africa
16	*Trogoderma granarius* Everts	Coleoptera	Dermestidae	Mainly cereals and some pulses	Across Africa
17	*Carpophilus dimidiatus* L.	Coleoptera	Nitidulidae	Groundnut, Maize, Rice	Mostly East and West Africa
18	*Tenebroides mauritanicus* L.	Coleoptera	Trogossitidae	Mainly cereals and some pulses	East, West and South Africa
19	*Oryzaephilus mercator* Fauvel	Coleoptera	Silvanidae	Groundnut, Rice	Mostly East Africa
20	*Oryzaephilus surinamensis* L.	Coleoptera	Silvanidae	Mainly cereals and some pulses	Mostly south Africa

No	Scientific name	Order	Family	Commodity	Country
21	*Zabrotes subfasciatus* (Boheman)	Coleoptera	Bruchidae	Beans, cowpea	West Africa
22	*Tribolium castaneum* Herbst	Coleoptera	Tenebrionidae	Cereals and Pulses	Across Africa
23	*Tribolium confusum* Jaquelin du Val	Coleoptera	Tenebrionidae	Cereals and Groundnut	Mostly East Africa
24	*Sitotroga cerealella* (Olivier)	Lepidoptera	Gelechidiae	Cereals	Across Africa
25	*Corcyra cephalonica* Stainton	Lepidoptera	Pyralidae	Primarily cereals, secondarily pulses	Mostly West Africa
26	*Ephestia cautella* (Walker)	Lepidoptera	Pyralidae	Mainly cereals and some pulses	Across Africa
27	*Ephestia elutella* (Hübner)	Lepidoptera	Pyralidae	Cereals	Mostly North Africa
28	*Ephestia kuehniella* Keller	Lepidoptera	Pyralidae	Many cereals	Across Africa
29	*Myelois ceratoniae* Zeller	Lepidoptera	Pyralidae	Rice, flour, pulses	Mostly North Africa
30	*Plodia interpunctella* (Hübner)	Lepidoptera	Pyralidae	Many cereals and groundnut	Mostly south Africa

2.5. Damage and losses

Average grain weight loss for cereals and pulses in Africa stands at 20% (Youdeowei and Service, 1986; Philips and Throne, 2010). However, the ranges for grain damage and losses across Africa are very broad. Grain damage and losses could result from the attacks of insects, micro-organisms, rodents and birds. Mainly damage from insects is considered in this section. In Kenya, De Lima (1979) reported the main causes of damage and weight loss in maize to be insect pests (4.5%) and rodents (1.5%). Farmers in the Adamawa Region of Cameroon attributed 50%, 47% and 3% stored maize damage to insects, rodents and micro-organisms, respectively (Nukenine et al., 2002). Although grain losses could include non-storage losses (harvesting and drying, threshing and shelling, winnowing and transport) and storage losses, only the storage losses in traditional systems are given consideration here. As explained earlier, traditional storage structures in Africa expose grains to serious insect infestations. Additionally, all small scale African farmers rely on sun drying to ensure that their crop is sufficiently dry for storage. If weather conditions are too cloudy, humid or even wet then the crop will not be dried sufficiently and losses will be high. This bad weather is frequent in wetter regions of Africa and could partly explain the higher grain damage level in the continent compared to those of the developed world. Tadesse and Eticha (1999) cited many studies on stored maize damage and losses in Ethiopia. Damage ranged between 11 and 100% and weight loss between 2.9 and 20% for storage periods of 2-12 months. In Eritrea, The germination loss due to the attack of storage pests on cereals and pulse grains ranges from 3-37 and 4-88 %, respectively (Haile et al., 2003). The weight loss for these grains also ranges from 4.4-14 and 9-29% for cereals and pulses respectively. During the usual 5-12 month storage period of grains in the Sudan and Guinea Savanna of Nigeria insect damage ranged from 40-60% for unthreshed sorghum and cowpea, to 36-55% for wheat grains (Ivbijaro, 1989). On-farm physical losses in grain weight were crudely estimated to range from 10% after one storage year to more than 30% over longer storage periods in Namibia (NRI, 1997). With the introduction of Prostephanus truncates (Horn) (Coleptera: Bostrichidae) average dry weight losses of farm-stored maize in Togo were estimated to have risen from 7 to 30%, for a storage period of 6 months (Pantenius, 1987; Richter et al., 2007). In Kenya, weight loss of stored maize increased from 4.5 to 30%, 20 years after the introduction of P. truncatus in the country. Delobel (1988) reported 60% groundnut damage caused by C. serratus after 10 months of storage in some traditional granaries in Congo Brazzaville. In this country a single granary containing cereals or pulses can be infested by up to 10 insect pests leading to 100% grain damage (Mikolo et al., 2007).

2.6. Stored product protection measures

Farmers in Africa predominantly use traditional methods in the management of stored product insects from time immemorial. Some farmers are also attracted to the use of synthetic insecticides. Nonetheless, many farmers apply no protection measures in their storage structures. Approximately 50% of farmers in Benin do not do anything to counter storage problems (Hell et al., 2000). All the farmers interviewed in Northern Ethiopia apply one or more management practice to stored maize, whereas 23% in the South of the country applied none (Tadesse and Eticha, 1999). In the Ngaoundere area of Cameroon, 47% of farmers were unable to protect maize stocks (Nukenine et al., 2002).

2.6.1. Traditional methods

The use of traditional stored product protection methods is very popular among small-scale farmers in Africa. The methods are numerous, diverse and widespread in the continent, with regional and country particularities. In Ethiopia alone, Tadesse and Eticha (1999) reported 25 traditional management practices for stored maize. Eighty-eight percent of the farmers in the North Central Regions of Namibia use traditional methods like ash or leaves in the protection of stored pearl millet (Keyler, 1996). Farmers in Uganda use banana juice, pepper, Mexican marigold, Tagetes minuta L. and eucalyptus leaves for bruchid control in storage (Giga et al., 1992). Belmain and Stevenson (2001) presented a list of 16 plants commonly used by farmers in northern Ghana for stored product protection. The leaves, flowers, seeds or roots in whole, decoction, powder extract forms are admixed or layered with the grains. Tapondjou et al. (2000), Nukenine et al. (2003) and Ngamo et al. (2007) reported over 20 insecticidal plant species in Cameroon with most of them being employed in storage protection by rural farmers.

Animal wastes such as goat and cow urine or dung are also used in the management of storage pests. For example, farmers in parts of Tanzania and the Sahel stored beans in sacks soaked and dried in goat urine which provided protection against storage pests (Gahukar, 1988).

2.6.2. Synthetic chemicals

The use of chemical insecticides in the form of sprays, fumigant or dusts against grain pests is common in large scale farms. Due to their rapid action, small-scale farmers are also attracted to these chemicals and those who have access to them are beginning to reduce the use of, or even abandon plant materials, which are lower in insecticidal efficacy. In some parts of Ethiopia (Tadesse and Eticha, 2000), Benin (Hell et al., 2000), Cameroon (Nukenine et al., 2002) and Eritrea (Haile, 2006), 70, 50, 23, and 12% of the farmers, respectively, treated their grains with synthetic chemicals. The usual chemicals recommended for stored product protection are employed, but also insecticides meant for the treatment of field crops like cotton or those internationally banned like DDT, are used by farmers in countries like Cameroon, Benin, Eritrea, etc. (Haile, 2006).

3. Trends in stored product protection

Owing to a lack of access to literature (electronic database and hard copies) in Cameroon, basically only the abstracts of all the articles published in the Journal of Stored Products Research from 1965 to 2009 have been consulted. This may be far from being exhaustive, but the journal is the single source of the most comprehensive published literature on stored product protection in the world. However, whenever possible reference is made to other publication sources.

3.1. Country of researchers

From Table 3, most research on stored product protection in Africa is published by researchers from Nigeria, Kenya, Cameroon and Benin. Benin is a small country but has a research centre of the International Institute of Tropical Agriculture, leading to their presence among the top African countries publishing on stored product protection. Africans also publish more articles in the Journal of Stored Product Research than Asians, although overall, Asians are likely to have much more research in the area than Africans. This is because Asian countries as compared to their African counterparts have far more scientific journals.

Table 3 Number of research papers concerning stored product protection for insects, micro-organisms and rodents in Africa, published in the Journal of Stored Products Research from 1965 to 2009.

Country	Papers in Journal of Stored Product Research
Nigeria	25
Kenya	9
Cameroon	9
Benin	7
Ghana	4
Senegal	4
Togo	4
Zimbabwe	3
Egypt	2

Country	Papers in Journal of Stored Product Research
Ethiopia	2
Tanzania	2
Burkina Faso	2
Morocco	1
Rwanda	1
Uganda	1
Zambia	1
Others (country not mentioned)	3
Africa	81
Asia	63
World	533

3.2. Commodity

More research on stored product protection seems to have been done on cereals than pulses in Africa (Table 4). Most of the research works were done after the year 1980. Maize for cereals and cowpea for pulses have been at the forefront of research. The last decade compared to the previous ones has been a flourishing period for maize protection research.

Table 4 Number of research works concerning stored product protection for different commodities in Africa, published in the Journal of Stored Products Research from 1965 to 2009

Types	commodity	Period (range)	Grouped years	# articles
cereal	maize	1970 - 2009	-	27
			1965 - 1979	2
			1980 - 1999	9
			2000 - 2009	16
	wheat	1969 - 2000	-	7
			1965 - 1979	3
			1980 - 1999	1
			2000 - 2009	3
	sorghum	1967 - 1980	-	4
			1965 - 1979	2
			1980 - 1999	2
	rice	2007	-	1
			2000 -2009	1
pulses	cowpea	1969 - 2009	-	22
			1965 - 1979	7
			1980 - 1999	13
			2000 - 2009	2
	bean	1970 - 2009	-	7
			1965 - 1979	1
			1980 - 1999	2
			2000 - 2009	4
	groundnut	1978 - 2006	-	4
			1965 - 1979	1
			1980 - 1999	0
			2000 - 2009	3
	Bambara groundnut	2001 -2003	-	
			2000 - 2009	3

3.3. Storage structures

Originally storage structures in the continent where made of only plant materials and mud. This trend is changing as a few farmers have replaced or are replacing mud rhombus with metal silos and plant material-woven cribs with those built of timber and corrugated iron roof. Most research in the late 1960s to the 1970s was focused on assessment of the prototypes of storage structures (Gilman and Boxall, 1974). Later research to date, have focused on improving traditional granaries for better durability, air-tightness, etc. (Adetunji, 2007).

3.4. Storage pests

Callosubruchus maculatus (F.) and Sitophilus zeamais Motschulsky which respectively attack the most important pulse (cowpea) and cereal (maize) in Africa are leading in research works. There are more research in Africa on *S. zeamais* than *S. oryzae*, but this trend is reversed when the entire world is considered (Haines, 2000). This is because *S. zeamais* is more of a pan-tropical species while S. oryzae is more cosmopolitan. *Tribolium* spp., *P. truncatus*, *Acanthoscelides obtectus* (Say) are also serious insects in the African stored product research landscape. Research on these insects has been on the rise from the 1960s to date. More research is focused on control measures rather than pest biology, infestation and ecology.

3.5. Control methods

Botanical insecticides, natural chemical products based on powders, extracts or purified substances of plant origin and physical control methods like manipulation of the temperature and humidity of the storage environment plus grain drying, are topping research on control measures for food storage in Africa (Table 5). Modest research has been carried out for synthetic chemicals, biological control and grain resistance to pests. Pest biology and inert dust have attracted very limited research in the continent.

Table 5 Periods when research on different control methods were reported in the Journal of Stored Products Research from 1965 to 2009.

Method	Period (range)	Grouped years	# articles
Inert dust	2000 - 2008	-	
		2000 - 2009	2
botanicals	1978 - 2009	-	26
		1965 - 1979	1
		1980 - 1999	6
		2000 - 2009	19
biological control	1997 - 2007	-	9
		1980 - 1999	2
		2000 - 2009	7
biology	1967 - 2006	-	3
		1965 - 1979	1
		1980 - 1999	0
		2000 - 2009	2
synthetic chemicals	1969 - 2009	-	12
		1965 - 1979	7
		1980 - 1999	3
		2000 - 2009	2
physical methods	1969 - 2009	-	26
		1965 - 1979	2
		1980 - 1999	10
		2000 - 2009	14
varietal resistance	2000 - 2003	-	7
		2000 - 2009	7

Inert dust: DE and Ash; Botanicals: whole leaves, powders, fractions, essentials oils, oils, solvent extracts; Biological control: parasitoids, predators, entomopathogens; Synthetic chemicals: lindane (1965, 1969), DDT (1967), malathion (OP) (1968, 1980), pyrethrin (P) (1969,1970, 1982), dichlorvos (1969), diazon (1969), methyl bromide (1970), permethrin (1982,1991), Fenitrothion (1975, 1980), tetrachlorvinphos, (1975, 1980), pirimiphos-methyl (1980), fenthion (1975), iodophenphos (1975), jodfendos (1980), deltamethrin (1991) phosphine (2004), allyl acetate (2004) Physical: temperature, humidity, drying (grain moisture)

Haines (2000) reported that, in the 1960s there was much published research on synthetic pesticides, but in the late 1990s there have been very few studies of synthetic insecticide efficacy. This trend is similar to what obtains in Africa (Table 5). From the late 1990s to date, instead storage pest control research has focused on alternatives, notably botanicals. Within the past five decades, 75% of research on botanical storage pest control in Africa was carried out during the last decade. The recent popularity in botanical research benefited from the well known demerits of synthetic insecticides (Haines, 2000). Botanical research in Africa is predominated by efficacy studies, with little works on mammalian toxicity and commercialization prospects as well as the bioactivity of individual phytochemicals.

Although still wanting, research on biological control involving arthropod predators and parasites in storage pests in Africa has been significant only within the last two decades (Table 5). Compared to the rest of the world, research in this area is not significant (Haines, 2000): The limited research in this area from the continent is dominated by works at international organizations, especially the International Institute of Tropical Agriculture, GTZ and FAO. There is also a paucity of research on inert dust in Africa, especially diatomaceous earth, compared to the rest of the world. These few studies were carried out during the last decade (Mvumi and Stathers, 2003; Demissie et al., 2008)

4. Concluding remarks

The majority of farmers in Africa store grains in traditional granaries which are flawed by structural and functional inadequacies, calling for an improvement of these structures. The process must take into consideration the technologies of the farmers. The farmers will readily accept a concept or technology that builds up or improves that which they are used to rather than one which imposes a totally new idea. For example, the mud rhombus could be replaced by cribs made of brick or concrete blocks and woven baskets by metal bins. Farmers, who already use improved granaries and experienced less pest damage in storage, should be encouraged to convince their friends to do same. The grouping of farmers into cooperatives and the construction of flawless community warehouses should be given priority.

African scientists have been less interested on research concerning the biology and ecology of storage pests, even though less is known about these pantropical species. Such research works are indispensable for the development of sound IPM strategies for such systems.

There is still the use of banned synthetic pesticides by some farmers in different African countries. This practice should be abandoned. As part of their duties, phytosanitory workers should monitor pesticide use in grain storage structures and sensitize the farmers of the dangers involved, for the abandonment to be effective. Most synthetic insecticides are produced in the temperate world where efficacy tests are done. African researchers should engage in field trials of such chemicals under African condition, especially as the effective dose may be lower under tropical conditions, compared to temperate conditions, thus reducing the overall quantity of each pesticide in Africa.

Many scientists in Africa are more concerned with research on determining the insecticidal efficacies of botanicals, while making unverified assumptions about their effects on operators and consumers. Such generalizations are clearly fallacious since many botanicals in crude and pure forms (e.g. opium, nicotine, and curare) have pharmacological, hallucinogenic or acute toxicity effects on humans and other organisms.

Despite the wealth of research on botanicals in Africa, practically no commercial product has emanated from the continent in the past three decades. Instead of broadening the spectrum of the tested plant species, future research should focus on a few plants and insist on their propulsion through the production chain.

More research needs to be focused on diatomaceous earths, both local and imported as these products may prove useful in stored product protection in the dryer areas of Africa.

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